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Research performed at Columbia University, in which etch-defined features were fabricated in multiple quantum well semiconductor material, is described. Photon-assisted neutral atom etching was demonstrated to produce damage-free features in GaAs-based quantum well material. The technique was applied in the fabrication of a single quantum well circular ring laser with low-loss etched sidewalls. The photoluminescence efficiency of magnetron reactive ion etched features was also investigated as a function of rf power and etching time. Low-temperature electron-beam enhanced etching and chemically assisted ion beam etching were characterized and applied to the fabrication of nanometer-sized features in III-V semiconductor material.

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## Table of Contents

1. Abstract 3

2. Summary of Results 4

    2.1 Studies of Low-Damage Neutral Atom Etching 4

    2.2 Damage Assessment Studies of Ion Beam Based Etching 5

3. Publications 5

4. Technical Reports Published 6

5. Inventions 6

6. Degrees Supported and Degrees Earned 6

# ABSTRACT

Research performed at Columbia University, in which etch-defined features were fabricated in multiple quantum well semiconductor material, is described. Photon-assisted neutral atom etching was demonstrated to produce damage-free features in GaAs-based quantum well material. The technique was applied in the fabrication of a single quantum well circular ring laser with low-loss etched sidewalls. The photoluminescence efficiency of magnetron reactive ion etched features was also investigated as a function of rf power and etching time. Low-temperature electron-beam enhanced etching and chemically assisted ion beam etching were characterized and applied to the fabrication of nanometer-sized features in III-V semiconductor material.

## 1. STATEMENT OF PROBLEM STUDIED

The electronic and optical properties of ultrasmall semiconductor devices have a strong dependence on the sidewall quality of the fabricated features. The sidewall quality is usually degraded through damage caused by the bombardment of energetic particles during dry etching. The development of etching techniques which minimize sidewall damage is therefore necessary for the fabrication of ultrasmall semiconductor devices.

Several etching techniques were investigated in the fabrication of submicron-scaled structures in III-V based semiconductor material. Photon-assisted and electron beam-assisted neutral atom etching are low-damage techniques, which were used to fabricate features with negligible sidewall damage. Magnetron reactive ion etching (MIE) and chemically assisted ion beam etching (CAIBE) are techniques that utilize bombarding ions and were investigated for producing ultrasmall structures with minimal damage.

## 2. SUMMARY OF RESULTS

### 2.1 Studies of Low-Damage Neutral Atom Etching

A photon-assisted cryoetching process was developed, in which laser irradiation at 193 nm was used to dissociate physisorbed chlorine on a cryogenically cooled sample to react with the underlying substrate. To evaluate this technique's pattern transfer capability, GaAs samples were patterned by electron beam lithography with different masking materials. While $Si_3N_4$ masks were found to be inadequate for small-scale pattern transfer, Cr/Au and Ni masks were successfully used to fabricate structures down to 200 nm lateral size. Multiple quantum well material, consisting of GaAs/$Al_{0.3}Ga_{0.7}As$ layers was also etched for a range of feature sizes. The photoluminescence efficiency of those structures was examined as a function of feature size and was found to be the same as for wet etched features. This indicates that the photon-assisted cryoetching process induces little or no damage to the feature sidewalls. The cryoetching technique was applied in the fabrication of an InGaAs single quantum well circular ring laser that emitted ~14 mW of single frequency output. The electron beam-assisted etching method, which also avoids heavy ion bombardment of the substrate, was characterized for GaAs samples as a function of temperature and beam current. Etching was demonstrated down to a temperature of -40

°C, at which isotropic, thermal etching of the chlorinated GaAs surface is suppressed and vertical sidewall profiles are obtained.

### 2.2 Damage Assessment Studies of Ion Beam Based Etching

Magnetron reactive ion etching was employed for the fabrication of submicron features in $GaAs/Al_{0.3}Ga_{0.7}As$ multiple quantum well material. The MIE etching was performed by George McLane at the Army Research Laboratory at Ft. Monmouth, for feature sizes ranging between 250 and 2000 nm, and for various rf power densities and etch times. Luminescence spectroscopy carried out on the etched samples indicated that the features etched at higher power densities (and greater ion impact energies) displayed less severe surface damage than features etched using lower rf power. This result is attributed to a better defined directionality of the bombarding ions, and therefore fewer ion-sidewall collisions, at high energy. At lower power densities, the etching became less anisotropic and incurred greater damage to feature sidewalls. Therefore, by controlling the rf power, it is possible to "tune" the degree of damage to the etched structures. A study of the morphological properties of MIE-etched nanoscale (<100 nm) structures was also initiated with the utilization of carbon nanotube tipped atomic force microscopy for high sensitivity diagnostics. The CAIBE etching of ultrasmall features was carried out and characterized for GaSb substrates as a function of chlorine flow rate and ion beam current density. The masking material for the GaSb samples consisted of 60 nm thick Cr, patterned using a scanning electron microscope with an external control option that was adapted for electron beam writing. The resultant etched GaSb structures exhibited good sidewall verticality and morphological properties.

## 3. PUBLICATIONS

1. M. B. Freiler, M. C. Shih, R. Scarmozzino and R. M. Osgood Jr., "Excimer Laser Induced Cryoetching of GaAs and Related Materials," Mat. Res. Soc. Symp. Proc. 279, 843-848 (1993).

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3. M. C. Shih, M. Hu, M. B. Freiler, M. Levy, R. Scarmozzino and R. M. Osgood Jr., I.W. Tao, and W.I. Wang, "Fabrication of an InGaAs Single Quantum Well Circular Ring Laser by Direct Laser Patterning," Appl. Phys. Lett. 66, 2608 (1995).

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8. E. Kim, G. Whitesides, M. B. Freiler, M. Levy, J.-L. Lin and R. M. Osgood Jr., "Fabrication of Micrometer-Scale Structures on GaAs and GaAs/AlGaAs Quantum Well Material Using Microcontact Printing," Nanotechnology 7, 266-269 (1996).

9. G. Nagy, R. Ahmad, M. Levy, and R.M. Osgood, Jr., "Chemically Assisted Ion Beam Etching of Submicron Features in GaSb," submitted to Appl. Phys. Lett.

## 4. TECHNICAL REPORTS PUBLISHED

None

## 5. INVENTIONS

None

## 6. PERSONNEL SUPPORTED AND DEGREES EARNED

Michael Freiler, Ph.D. earned

Peter Lasky, Ph.D. expected 1997